LOY, BRYAN, M.S. The Effects of Self-Regulatory Depletion on Perceived Exertion During 30 minutes of Treadmill Exercise. (2011)
Directed by Jennifer L. Etnier. 70 pp.

The purpose of this research was to determine if self-regulatory strength depletion induced by performing a modified Stroop task would influence rate of perceived exertion (RPE) during 30 minutes of treadmill exercise. Research indicates that self-regulatory strength can be depleted and performance on subsequent tasks that require self-regulation can be diminished (Muraven and Baumeister, 2000). Participants completed the modified Stroop task (experimental condition) and the color word task (control condition) before performing treadmill exercise at ventilatory threshold for 30 minutes. The modified Stroop task and the color word task were completed on separate days, and the order that participants completed tasks was randomly assigned. Self-regulatory strength depletion did not impact RPE, $F(1,12) = 1.63$, $p > .05$, partial $\eta^2 = .12$, or exercise heart rate, $F(1,12) = .01$, $p > .05$, partial $\eta^2 = .00$. Yet experiencing self-regulatory strength depletion on the first day resulted in significantly lower RPE when self-regulatory strength was not depleted on the second day, $F(1,11) = 9.01$, $p < .05$, partial $\eta^2 = .45$. The results of this study have implications for perceptions of future exercise sessions when self-regulatory strength is or is not depleted.

THE EFFECTS OF SELF-REGULATORY DEPLETION ON PERCEIVED EXERTION DURING 30 MINUTES OF TREADMILL EXERCISE

by

Bryan Loy

A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Greensboro
2011

Approved by

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Committee Chair

To the past teachers and educators who awakened my love of learning.
Thank You.

APPROVAL PAGE

This thesis has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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ACKNOWLEDGEMENTS

First and foremost, I owe a great deal of gratitude to Dr. Jennifer Etnier for providing guidance throughout the project.

I also thank my thesis committee members, Dr. Eric Hall and Dr. Wally Bixby. Both have gone beyond what would normally be expected of them to help foster scholarship outside of their own institution. I sincerely appreciate the commitment.

Finally, a special thanks to my family and friends for supporting me emotionally throughout the project. I am especially grateful for Mom, Dad, Suzanne Capehart, and Kevin Fisher for simply being great friends during this process, and throughout my life in general.

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CHAPTER I

INTRODUCTION

Physical inactivity is a major problem in the United States, with only 49% of the population aged 18-64 meeting the minimum physical activity guidelines recommended by the American College of Sports Medicine (ACSM; Haskell et al., 2007). Individuals may not meet the ACSM guidelines and may struggle to adhere with exercise for a variety of reasons. These may include a perceived lack of time (Lian, Gan, Pin, Wee, & Ye, 1999), low self-efficacy (Booth, Owen, Bauman, Clavisi, & Leslie, 2000), and environmental barriers (Lian et al., 1999). In short, there are many reasons that individuals may not adhere to exercise, but successfully maintaining an exercise routine may be related to the ability to delay gratification and exert control over desires. In psychology, this is known as self-regulation, which describes an individual's ability to resist temptation and control behavior in order to reach goals or meet societal expectations (Baumeister, Vohs, & Tice, 2007). Self-regulation is important when individuals must resist impulses and instead act in ways that are consistent with individual goals or societal expectations. It can be relieving in the short term to stop exercising and rest tired muscles, but many want to push past this level of discomfort in order to get stronger, improve health, lose weight, or reach other long term goals.

When individuals self-regulate they are continuously assessing their current thoughts and behaviors to insure consistency with societal expectations and their own long-term goals. If there is a mismatch, individuals who are self-regulating try to control the unacceptable thought or behavior and then replace it with a more acceptable action (Baumeister & Heatherton, 1996). Individuals may need to self-regulate when they are trying to act friendly with rude people or while resisting the urge to abuse drugs. But it is tiring to continuously change behaviors and thoughts in order to meet societal goals or standards. It actually appears that individuals can only successfully self-regulate for a short amount of time before fatigue limits this ability (Baumeister, Vohs, & Tice, 2007).

The limited strength model of self-regulation suggests that the ability to control the self relies on a limited resource or energy supply that can be depleted (Baumeister et al., 2007). It may be helpful to think of self-regulatory abilities as a muscle that can become fatigued or tired. Fatigue may inhibit the process that brings the current self back in accordance with the ideal self or goals of that self (Muraven & Baumeister, 2000). Research studies have supported the limited strength model by showing that participants perform worse on a second task that requires self-regulation after completion of a first, albeit different, task that also requires the same ability (Baumeister & Heatherton, 1996; Baumeister et al., 2007, 2007; Bray, Martin Ginis, Hicks, & Woodgate, 2007). In one such study Muraven, Tice, and Baumeister (1998) examined performance on a handgrip task after some individuals had been depleted of self-regulatory strength from a task that required emotional control. Muraven et al. first determined how long participants could hold a handgrip in place, which is a task that requires self-regulatory strength (Rethlingshafer, 1942). They then performed this same task following either emotional control (self-regulation depleting) conditions or a control condition. Results showed that participants in self-regulation depleting conditions were able to hold the handgrip for significantly less time on the second trial than on the first trial, whereas there was no difference for the control group between the first and second trials. This finding suggests that controlling emotion decreased self-regulatory strength which then led to diminished capacity on another task requiring self-regulation.

Research has also demonstrated that performing a mental task that depletes self-regulatory strength can impact physical performance. Bray, Martin Ginis, Hicks, and Woodgate (2007) measured how long students could maintain 50% of their maximum voluntary contraction on an isometric handgrip dynamometer after they had completed the Stroop task, which depletes self-regulatory strength. Participants who were asked to complete the Stroop task reported significantly more frustration and held the second isometric handgrip for a significantly shorter period of time than participants in a control condition.

The work of Bray et al. (2007) is important in increasing our understanding of how a cognitive task requiring self-regulation can impact physical performance. But the mechanisms that can help explain how self-regulatory strength depletion impacts exercise performance are still not clear. Measuring the difficulty of exercise using the Rate of Perceived Exertion (RPE) scale may help identify these mechanisms. Rather than simply monitoring the physiological response associated with exercise, the RPE scale allows for the examination of how the exerciser actually interprets the difficulty of exercise (Meeusen et al., 2009).

Although RPE is obviously thought to be reflective of the participant's physiological responses, there is evidence that RPE may be influenced by self-regulatory strength depletion independent of other physiological variables. Marcora, Staiano, and Manning (2009) asked two groups of cyclists to work at 80% of peak power output until volitional exhaustion. The experimental group had been depleted of self-regulatory strength via a vigilance task and a manipulation check assured that participants were mentally fatigued based on scores from a mood questionnaire. Those in the experimental group reached exhaustion during exercise sooner than individuals in the control condition. Exhaustion was based on RPE scores that were found to be independent of physiological indices of exhaustion. Thus, the authors concluded that the depletion of self-regulatory strength is a limiting factor in exercise tolerance independent of cardiorespiratory and muscular mechanisms.

The purpose of this study is to replicate and extend the findings of Bray et al. (2007) who have shown that completing self-regulation tasks before exercise can decrease exercise performance. Marcora et al. also used a vigilance task as the manipulation with time to exhaustion during cardiovascular exercise (cycle ergometer) as the outcome. This study was not designed to test self-regulatory depletion effects per se; however, the premise underlying the study was that the vigilance task would induce cognitive fatigue that would be reflected in the individual's decreased ability to perform the exercise. Bray et al. employed a modified Stroop color word task that depleted self-regulatory strength to test the effects on the amount of time that participants could hold a handgrip. This study was designed to test the self-regulatory depletion hypothesis and included both a manipulation and an outcome measure that have been established as related to self-regulatory strength. However, the effects of self-regulatory strength depletion on time to exhaustion while performing handgrip exercise might not generalize to other types of exercise. Therefore, the purpose of the present study is to test the effects of a manipulation that is established as a means of depleting self-regulatory strength on exercise behavior. Tying the self-regulation handgrip literature (Bray et al., 2007; Muraven et al., 1998) with the work of Marcora et al. (2009) will allow for an assessment of the effects that self-regulatory strength depletion has on exercise performance and will provide an indication of the extent to which cardiovascular exercise itself is a task that requires self-regulation.

Past researchers (Bray et al., 2007) have used a modified Stroop task to deplete self-regulatory strength and a color word task as a control, and the same protocol will be used in the present study. Since self-regulatory tasks require mental strength (Muraven & Baumeister, 2000) and because RPE is impacted by mental fatigue (Hutchinson & Tenenbaum, 2006), it is hypothesized that participants depleted of self-regulatory strength (experimental condition) will report higher RPE during 30 minutes of treadmill exercise at ventilatory threshold than non-depleted participants (control condition).

CHAPTER II

REVIEW OF LITERATURE

The American College of Sorts Medicine (ACSM) recommends that adults aged 18-64 should do 30 minutes of moderately intense exercise on five days per week, or 20 minutes of vigorous intensity exercise on three days per week (Haskell et al., 2007). Some people may find it easy to exercise at these intensities and durations, but others may find such exercise to be more painful, tiring, and difficult. The constructs of pain, fatigue, or exertion levels are not the same constructs to every exerciser. In fact, two people may be doing the exact same exercise, in regards to the individual physiological intensity, but interpret the difficulty of the exercise in completely different ways (LaCaille, Masters, & Heath, 2004). In many ways, what people think they are doing is possibly more important than what people are actually doing physiologically in regards to exercise adherence and performance.

The discrepancy in pain interpretation between exercisers may be explained by the Gate-Control Theory (Melzack & Wall, 1965), which suggests that each dorsal horn of the spinal cord operates like a gate that may or may not allow feelings from the periphery to reach a conscious level. In other words, the brain can “choose” to attend to certain feeling or pain impulses but ignore others. The system makes its “choice” based on three branches of interpretation. The sensory-discriminative branch interprets the location and intensity of the pain feeling. The cognitive-evaluative branch evaluates what the feeling means, and the motivational-affective branch makes an emotional response and decides if it is necessary to avoid the source of the pain. Thus, the interpretation of pain or exertion during exercise is more than a direct reading of physiological signals. The sensations can be altered based on a variety of cognitive and emotional factors.

Although all of the branches are integral parts of pain interpretation, the present review will focus on the cognitive-evaluative branch. One cognitive-evaluative factor that impacts pain interpretation or fatigue is the cost and reward of performing the activity. If perceived rewards outweigh perceived costs, the behavior will be performed and fatigue will likely not be perceived. But when perceived costs are greater than perceived rewards, the individual may stop the behavior and may attribute their decision to the experience of fatigue. The onset of fatigue may be interpreted by the exerciser as a signal that the behavior is maladaptive and that the behavior is not leading to the desired goal.

The ability to delay gratification and reach long-term goals in other pursuits unrelated to exercise may be correlated with how well individuals are able to handle fatigue during exercise. This ability is known as self-regulation, and is a skill that allows humans to control and direct actions (Forgas, Baumeister, & Tice, 2009). Self-regulation is important when individuals must resist initial temptation and instead act in ways that are more acceptable in society or will be more worthwhile in the long term. In the realm of exercise, this means pushing past any acute pain or fatigue in order to benefit from physiological changes related to other long term goals.

The self-regulation process can be conceptualized as a feedback-loop model in which individuals are constantly monitoring their present behaviors and thoughts to insure a match with standards, goals, and their ideal self. If monitoring suggests that an individual's ideals do not match the current state or self, a process is started that brings the current self back in accordance with the ideals (Baumeister & Heatherton, 1996). This could involve turning off the television to work on homework and get better grades, or resisting chocolate chip cookies when dieting. But it is challenging and fatiguing to continuously self-regulate and direct behaviors and thoughts.

Current research suggests that self-regulation abilities are limited by a finite reserve of energy or strength (Baumeister & Heatherton, 1996; Baumeister, Vohs, & Tice, 2007; Bray, Martin Ginis, Hicks, & Woodgate, 2007). The limited strength model suggests that self-regulation ability is like a muscle that can become fatigued or tired. This fatigue may inhibit the ability to engage in processes that will bring the current self back in accord with the ideal self (Muraven & Baumeister, 2000). Also much like a muscle, the limited strength models suggests that self-regulation abilities can be trained so that an individual can self-regulate for a longer period of time without experiencing diminished self-regulation capabilities.

Muraven, Baumeister and Tice (1999) examined how training in control can be used to increase self-regulatory strength over time. The authors first assessed self-regulatory strength by recording how long participants could maintain an isometric handgrip task after self-regulatory strength had already been depleted through a thoughtsuppression task. Performance on the handgrip task is accepted as a measure of self-regulatory strength (Rethlingshafer, 1942). Muraven et al. then randomized participants to either monitor and improve posture, control mood, record eating behaviors, or to not participate in any self-regulatory behavior for two weeks. After the intervention period, those who had routinely participated in self-regulatory exercise performed the handgrip task after self-regulatory strength depletion longer than the control group.

Research studies have also supported the limited strength model by showing that participants perform worse on a second task that requires self-regulation after completion of a first, albeit different, task that also requires the same ability (Baumeister & Heatherton, 1996; Baumeister, Vohs, & Tice, 2007; Bray, Martin Ginis, Hicks, & Woodgate, 2007; Muraven, Tice, & Baumeister, 1998). In one such study Muraven et al. (1998) examined performance on a handgrip task after some individuals had been depleted of self-regulatory strength by performing a task that required emotional control. Muraven et al. first determined how long participants could hold a handgrip in place. All participants were then shown a three minute clip of a documentary about environmental disasters, but the experimental and control groups were given different instructions concerning how they should view the documentary. One experimental group was told to increase their emotional response to the film, another experimental group was told to hide their emotions, and a third control group was not given any instructions about how to emotionally respond to the documentary. Past research has indicated that emotional regulation is effortful and taxes self-regulatory abilities (Wegner, 1994). In this particular study, both experimental groups needed to emotionally regulate since they were asked to either exaggerate or inhibit their normal emotional reaction. After the viewing, participants rated the amount of effort required to control their emotions during the documentary and the experimental groups both reported that it took significantly more effort to watch the documentary than the control group. Although not significant, the increased emotion group reported more effort than the decreased emotion group in watching the documentary. Finally, all participants performed the handgrip task again after the documentary and the increased emotion and decreased emotion groups held the grip for significantly less time than their first trial, whereas there was no difference for the control group between the first and second trials. This finding suggests that controlling emotion during the film decreased self-regulatory strength that led to diminished capacity on another task requiring self-regulation (handgrip).

In a similar study, Bray, Martin Ginis, Hicks, and Woodgate (2007) asked 49 sedentary undergraduate students to maintain 50% of their maximum voluntary contraction on an isometric handgrip dynamometer before and after either a modified Stroop task or a color word task. The modified Stroop task was meant to deplete self-regulatory abilities and the color word task was not. The modified Stroop task consisted of color words written in mismatched ink. For example, the word blue could be printed in green ink. Participants were instructed to report the ink color and not the text, except for words printed in red ink in which case participants were required to read the text and not report the color. In the color word task, ink colors and text matched and participants were instructed to read the text. Questions pertaining to fatigue, effort, pleasantness, and frustration were used to determine if the tasks depleted self-regulatory strength.

Participants who had performed the modified Stroop task reported significantly more frustration and held the isometric handgrip for a significantly shorter period of time than participants who had performed the color word task.

It appears that self-regulatory strength depletion may also impact exercise performance by diminishing the self-regulation abilities that individuals have to fight against the urge to stop. To study how this may occur, it is important to measure how difficult exercise feels to understand what an individual must regulate or control in order to continue exercising. The perceived difficulty of exercise is often measured using the rating of perceived exertion (RPE) scale. Borg (1982) developed the scale so that individuals could report their own perception of strain. The measure includes the numbers 6-20 with words such as "very light", "somewhat hard", "very hard", and "very, very hard" to help explain the number ratings. A 6 is indicative of no exertion and a 20 represents all-out exertion. The scale is not meant to reflect one particular indicator of exertion, but is rather meant to represent the combination of all factors interacting together in a global sense. These could include respiration rate, muscular fatigue, lactic acid accumulation, and even boredom. Rather than simply monitoring the physiological response associated with exercise, the RPE scale allows for the examination of how the brain actually interprets the difficulty of exercise (Meeusen et al., 2009).

There are numerous social-psychological factors that research has shown may impact RPE (Hall, Ekkekakis, & Petruzzello, 2005). Cognitive fatigue is one factor that may impact the ability to perform prolonged exercise at a high intensity and may increase

RPE (Marcora, Staiano, & Manning, 2009). Yet the relationship between cognitive fatigue (leading to diminished self-regulatory abilities) and RPE is largely understudied. Research has yet to explore the mediators between cognitive fatigue and elevated exercise RPE. It is also unknown what dose or type of cognitive fatigue will lead to an elevated exertion response during exercise. The purpose of this review is to consider what is known about the social-psychological factors that may influence RPE and to also consider the new possibility that cognitive fatigue (diminished self-regulatory strength) may influence RPE and exercise performance.

Social-Psychological Factors Influencing RPE

A variety of exercise factors may impact RPE, and individuals can either overestimate or underestimate their exertion level. Among the factors studied include exercise setting and activity preference. LaCaille, Masters, and Heath (2004) asked participants to run five kilometers either on a treadmill, indoor track, or on a flat outdoor road course. Participants ran the slowest and reported the highest RPE while running on the treadmill. Conversely, the lowest RPE was given for the outdoor run, and participants also reported feeling less exhausted after the run. Ratings of positive engagement, revitalization, tranquility, and course satisfaction were also highest after the outdoor run. Attention focus (association or dissociation) was not found to impact the exercise setting effects.

Exercisers often report feeling better when they do the type of exercise they are most familiar with or like the most. Bixby and Lochbaum (2008) examined this phenomenon by asking 42 female college students to complete an exercise preference questionnaire. Participants then completed their most preferred activity, least preferred activity, and a control condition. This was done in a random order and each participant completed one activity per day. Affect and RPE were measured before, during, and after each activity. Participants reported more positive affect during and after their most preferred activity, as compared to their least preferred activity or the control condition. Exercisers also had higher RPE during the least preferred activity as compared to what they reported during the most preferred activity. This finding suggests that exercise preference and the enjoyment experienced during and after activity could influence RPE.

Attention focus during exercise has also been shown to impact RPE. When exercising, individuals may either associate or dissociate. Association is broadly defined as attending to the present activity and monitoring bodily signals. Exercisers may then adjust movement or behavior in response to feelings of exertion in order to meet the goals of the exercise session. Dissociation involves attending to or thinking about anything besides the exercise session. This is done to help time pass and prevent the recognition of the pain and exertion associated with exercise (Lind, Welch, & Ekkekakis, 2009). While ignoring pain sensations through dissociation may certainly be important in lowering RPE, associative thoughts may actually change the physiological response at an absolute workload. Hatfield, Spalding, Mahon, Slater, Brody, and Vaccaro (1992) asked cross-country athletes to run at ventilatory threshold for 36 minutes. Participants were asked to do three attentional tasks during the run and the order of the tasks was randomized and counterbalanced among the group. During the run, participants received minute ventilation and EMG data (feedback segment), performed a reaction time and anticipation task (distraction segment), and only ran and were not given a task upon which to focus attention (control segment). During the feedback segment, participants demonstrated a reduction in respiration rate and an increase in tidal volume, as compared to the distraction and control segments. During the feedback and distraction segments participants also reported lower RPE than during the control segments. The decrease in respiration rate during the feedback segment may have contributed to lower RPE since past research has suggested that decreases in respiration rate are related to lower RPE (Morgan, 1981). During the distraction segment, participants may have reported lower RPE than when completing the control segment simply because they were asked to actively think about something else besides the exercise. Thus, focusing on breathing can decrease respiration rate and increase tidal volume, and these changes are also related to a lower RPE.

Attention focus may also be impacted by the frequency of RPE measurement. Corbett, Vance, Lomax, and Barwood (2009) had participants perform two sub-maximal running tests for 35 minutes, and participants ran at the same speed for each test. RPE was measured every 10 minutes for one condition, but after every minute for the second condition. Higher RPE was reported when RPE was measured more frequently. Interestingly, there was no difference in heart rate, VO_2, or respiratory exchange ratio between the conditions. The authors suggest that frequent measurement of RPE may lead exercisers to attend to their own perceived exertion to a greater extent and thus experience higher levels of perceived exertion.

RPE ratings at an absolute workload may also be influenced by personality variables. Hall, Ekkekakis, and Petruzzello (2005) examined the correlations of extraversion, behavioral inhibition, and self-efficacy with RPE during exercise at and below ventilatory threshold. High levels of trait extraversion and self-efficacy were correlated with a lower RPE at exercise below ventilatory threshold. Yet only behavioral inhibition, a personality trait characterized by a heightened awareness of punishment and negative affect (Gray, 1991), was positively correlated with RPE above ventilatory threshold. The authors concluded that at high intensity levels some psychological factors may no longer influence RPE because the sensations of physiological changes are so strong (Hall, Ekkekakis, & Petruzzello, 2005).

Cognitive Factors and RPE

It is apparent that many social-psychological factors may influence RPE in addition to various physiological sensations. But not all thoughts or sensations reach consciousness and actually impact RPE in any given situation. Much like the aforementioned social-psychological factors, RPE can be impacted by cognitive factors in ways that may or may not be directly impacted by physiological variables such as heart rate, lactic acid, concentration, or respiratory exchange ratio.

The brain is constantly evaluating fatigue and rating RPE based on a systematic analysis of energy cost and potential reward. Boskem and Tops (2008) suggest that the nucleus accumbens, amygdala, insula and anterior cingulate cortex are the brain regions responsible for making these judgments. For individuals to resist mental fatigue and continue in an activity, predicted rewards must be greater than the energy need to complete the task. Motivation is an important factor in this assessment, because if the perceived reward is not greater than the perceived cost of the activity, the individual may decide that the task is not worth completing and stop the behavior. In exercise settings, the important consideration is that the judgments of cost are based upon perceptions of energy available and may or may not be related to the actual energy that is available.

It is also possible for cognitive resources to become depleted. Research has suggested that depletion caused by performing a taxing cognitive task can negatively impact performance on subsequent activities involving the use of mental resources. Wright et al. (2007) examined the impact of high fatigue or low fatigue tasks on a subsequent mental challenge that was either related or unrelated to the first task. The first assignment either involved counting forward by one from 375 (low fatigue) or counting backward from 375 in increments of three (high fatigue). Heart rate and blood pressure ratings confirmed the difference between the conditions. Participants then either did a multiplication task (relevant to task 1) or were asked to circle the letter H on pages full of random jumbled letters (not relevant to task 1). Blood pressure was higher after the second task, but was greatest for the participants who had been fatigued during the first task. Findings also suggested that perceived difficulty of the assignment and perceived ability were negatively related to the heart rate and blood pressure markers of fatigue. These results indicate that fatigue impacts performance even on tasks that are not directly related to the activity that caused the fatigue.

Wright, Stewart, and Barnett (2008) replicated these findings using different cognitive tasks for assignment 1 and 2. For task 1 participants were assigned to either circle all Hs in a matrix of jumbled letters, or to only circle H's without the letters "A", "E", "I", "O", or "U" immediately before or after. Participants in either group were asked to circle one H every 3 seconds when given a verbal command. Circling all H's does not require self-regulatory strength, but circling only the H's without vowels immediately before or after does require such strength because participants must control the inclination to circle all H's and only circle H's that are in accordance with the rules. Participants were then asked to either complete the Stroop task or single-digit multiplication problems as their second task. The Stroop task requires the use of self-regulatory resources, but single-digit multiplication does not since participants only need to multiply (not add or carry digits) and are not required to inhibit responses as with the Stroop task. There were both time and condition effects for systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and rating of task difficulty. SBP, DBP, and MAP were all greater during the second task than the first, and participants who completed tasks requiring self-regulation for either task 1 or 2 exhibited higher SBP, DBP, and MAP than those who had completed tasks not requiring self-regulation. The implication is that mental fatigue may increase cardiovascular reactivity and positively impact ratings of perceived difficulty on tasks that involve the use of cognitive resources and the process of self-regulation.

Research has also suggested that cognitive fatigue can impact RPE independently of other physiological variables. Marcora, Staiano, and Manning (2009) asked two groups of exercisers to cycle at 80% of peak power output until volitional exhaustion. The researchers asked participants in the experimental condition to complete a reaction time and letter pattern recognition task for 90 minutes before exercise. The task required attention, working memory, and response inhibition and was meant to replicate the intense cognitive activities that students, soldiers, or workers often complete before participation in demanding physical activities. Participants in the control condition watched documentaries for 90 minutes before exercise. The documentaries were chosen so as to not induce changes in heart or mood. In fact, participants in the experimental condition exhibited significantly higher heart rate during the letter pattern recognition task than the control participants did during the documentaries. Exercisers in the experimental condition were also mentally fatigued based on scores from a mood questionnaire. In regards to exercise, participants in the experimental condition reached exhaustion sooner than individuals in the control condition. Exhaustion was defined as the point when pedal frequency was less than 60 rotations per minute for more than five seconds. The authors concluded that cognitive fatigue is a limiting factor in exercise tolerance independent of cardiorespiratory and muscular mechanisms. Cognitive fatigue during exercise is evident based upon higher RPE at the same physiological intensity.

Research has also indicated that high volumes of exercise that lead to overreaching may also negatively impact cognitive abilities. Rietjens et al. (2005) asked a group of seven well trained males to increase their training by doubling exercise volume and increasing intensity by 15% over a two-week period. This was done in hopes of inducing the overreaching state so that markers of overreaching could be examined. As expected, participants reported elevated training strain, monotony, and RPE during exercise in response to the increase. Reaction time was measured at baseline and after the two week training increase, and reaction times were slower than when measured at baseline. Rietjens et al. concluded that overreaching impacts cognitive speed and information processing. They further suggested that the change in reaction time (an indicator of cognitive fatigue and function), RPE, and mood may serve as predictors of overreaching and may be used to diagnose overreaching before the change in physiological factors is apparent via measurement.

In summary, Marcora, Staiano, and Manning (2009) have suggested that cognitive fatigue can impact exercise performance due to elevated RPE. Rietjens et al. (2005) have argued that prolonged exhaustion caused by exercise can negatively impact cognitive performance and that the overreaching state leads to higher RPE during exercise. These findings thus suggest that cognitive fatigue, RPE, and exercise performance are linked.

Future Research

The findings of Marcora, Staiano, and Manning (2009) are important in expanding the exercise and cognition literature. Yet this is the first study that has directly explored the influence of cognitive fatigue on exercise RPE and performance. This is a logical area of research because other studies have demonstrated that cognitive fatigue caused by one type of task can cause another unrelated task to feel more difficult (Wright, Stewart, & Barnett, 2008). Research has also suggested that exercise difficulty or RPE can be influenced by a number of psychosocial factors (Corbett, Vance, Lomax, &

Barwood, 2009). According to the Gate-Control theory (Melzack & Wall, 1965), RPE can also be influenced by cognitive factors, so it is logical to believe that cognitive fatigue could cause elevated RPE at an absolute workload.

In other words, it is clear that individuals can experience cognitive fatigue that limits subsequent performance in other cognitive tasks (Wright et al., 2007). It is also apparent that exercise performance can be impacted by an elevated RPE that is not always related to physiological variables. In fact, many psychological factors can impact RPE (Hutchinson & Tenenbaum, 2006). Researchers also cannot definitively say what types of activities cause cognitive fatigue and if or when this fatigue is actually apparent when individuals perform different exercise tasks. Furthermore, there is little understanding of the mechanisms that could help explain this phenomenon. A better understanding of the causes and mechanisms related to cognitive fatigue would advance the theoretical understanding of the relationship between cognitive fatigue, RPE, and exercise performance.

This is also an important question to study because of the real world implications. Individuals must have good social tact in order to be successful in relationships and even in many jobs. For example, servers in restaurants must be warm and helpful with customers to earn a good tip, even if these staff members are fatigued from the social and cognitive demands of their job. Individuals on a diet must resist splurging even when tired and stressed. Attorneys must be ruthless and convincing when facing the defense, even though they may feel exhausted from the efforts they have put in on their client's behalf. Accountants must be able to fix attention for long periods of time in order to not make costly errors or miscalculations. Further, it is important for waiters, attorneys, and others to maintain a regular exercise regimen for their physical and psychological health. But if these individuals perceive the demands of their job to be fatiguing, it is possible that this would impact their perception of the difficulty of exercising and this might limit their participation in future exercise (Martin Ginis & Bray, 2009). If this is the case, these individuals may want to avoid social interaction and cognitive exertion before exercise to avoid experiencing exaggerated fatigue and greater than normal levels of exertion. Of course there are many other variables associated with socializing or controlling behavior for a prolonged period of time that could impact exercise performance. But good research can control for many of these variables and it has still been suggested that cognitive fatigue may lead to elevated RPE independently of changes in physiological variables (Marcora, Staiano, and Manning, 2009). The phenomenon of cognitive fatigue has yet to be explored in a practical setting and future study could help advance both theoretical understanding of these constructs and influence exercise practices.

Future research should seek to confirm or deny the findings of Marcora et al. (2009), and tie them to research on self-regulatory strength depletion in order to demonstrate that exercise performance is impacted when self-regulatory strength is limited and that exercise itself is an activity requiring self regulation. Individuals probably realize that it is draining to manage emotions or resist impulses but may not necessarily believe that such behavior could impact exercise performance. But research (Hutchinson & Tenenbaum, 2006) now suggests that the body may be a more integrated system than this simplistic view posits and that self-regulatory strength depletion may influence RPE independently of other physiological factors (Marcora, Staiano, & Manning, 2009). Thus, it needs to be determined if individuals give higher RPE while running on a treadmill at a submaximal intensity after experiencing a reduction in self-regulatory strength when compared to the RPE given by participants who are not depleted. This future research should also use RPE during a submaximal exercise bout rather than assessing exercise to failure as in past studies (Bray et al., 2007; Marcora et al., 2009). This is because ACSM does not recommend that individuals exercise to failure to achieve health and fitness benefits (Haskell et al., 2007). Using measures of RPE rather than exercising to failure will provide better insight as to how self-regulatory strength depletion impacts exercisers trying to achieve ACSM guidelines. Answering this question will hopefully increase practical understanding concerning how mental fatigue may impact RPE and time to exhaustion in a physical performance setting.

CHAPTER III

METHODS

Participants

Undergraduate male and female students who were healthy enough to safely perform physical activity were recruited as participants. The AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire (Balady et al., 1998) was completed to determine if potential participants could engage in exercise without any unreasonable risk of physical harm. Participants with two or more cardiovascular risk factors or a history of symptoms that are contraindicated for exercise were excluded from the study on the grounds of non-qualification. Only participants who are not considered physically inactive on this screening questionnaire (individuals who do less than 30 minutes of physical activity on 3 days per week are considered inactive) were included in the sample. But, participants were not recruited who did more exercise than the ACSM minimum guidelines (3 days per week of vigorous intensity exercise or 5 days per week of moderate intensity exercise). Exercise habits were assessed over the two weeks prior to participants beginning the study with the Godin Leisure Time Exercise Questionnaire (Godin & Shephard, 1985). Based on the aforementioned exercise requirements, participants were required to score between 15 and 30 on the Godin to be eligible for the study. This helped standardize responses to exercise and insured that fitness level was not a variable (in addition to self-regulatory strength depletion) that significantly moderated

RPE during the 30 minute treadmill exercise session**.** Potential participants were screened using the AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire and Godin Leisure Time Exercise Questionnaire before they were scheduled to start the study. Before beginning the study, all participants read and signed an informed consent form that was approved by the institutional review board. Participants were not told the purpose of the study until after the third session. At that time, participants were debriefed, thanked for their participation, and asked not to discuss the study with others.

Design

A quantitative experimental design was used with a within-subjects design. The independent variable in the present study was self-regulatory strength depletion which was induced through completion of the modified Stroop task. The control condition was the color word task which does not deplete self-regulatory strength. Each participant did the modified Stroop task and the color word task on separate days, and the order that participants completed tasks was randomly assigned. After the respective task assigned for that day, participants completed 30 minutes of treadmill running, with a 6-minute warm-up and the last 24 minutes performed at ventilatory threshold. The dependent variables include RPE and heart rate reported during the treadmill exercise every three minutes.

Measures

Physical Activity

The National Health and Nutrition Examination Survey (NHANES; Williams & Wilkins, 1997) was used to more thoroughly assess physical activity habits over the two weeks prior to participating in the study. The survey consists of 20 different types of leisure time physical activity such as running, weightlifting, basketball, and cross-country skiing. If participants have completed an activity, they stated how many times over the past two weeks that they completed the activity and the average number of minutes for each session. Participants also stated if they had a small, moderate, large, or no increase in heart rate during the activity, or participants can state that they do not know.

Exertion

The Borg Scale of Perceived Exertion (Borg, 1982), or rating of perceived exertion (RPE), scale was used to measure the intensity of activity during exercise on the basis of perceived effort. The scale is based on physiological and behavioral measurements of physical exertion and performance. In this way, it can be used for exercisers to quickly and easily quantify different efforts. Work efforts are rated on a 6-20 scale with guide words to further clarify what each number rating of exercise should actually feel like. For example, 7 is equated to “Very, very light”, 11 is considered “Fairly light”, 13 is equated with “Somewhat Hard”, and 19 is called “Very, very hard”. The ratings should also roughly equate to one-tenth of the exerciser’s heart rate. For example, if a participant gives a rating of 11 their heart rate should be about 110. The correlation reported between RPE rating and heart rate is between 0.80-0.90 (Borg, 1982). The RPE scale has not been validated against other scales measuring perceived exertion, but itself is the gold standard measure for perceived exertion.

Activation Level

Heart rate was measured before and after the pre exercise task (modified Stroop or color word task) as an indicator of activation. Measures were also taken every three minutes during exercise and were used as a physiological indicator of effort. Any changes were judged relative to baseline measures that were taken before the pre-exercise task when the participant was seated comfortably and in a relaxed state for at least five minutes.

Fatigue

The Activation-Deactivation Adjective Checklist (ADACL) was also given before and after the modified Stroop task and color word task as a manipulation check. The ADACL (Thayer, 1989) is a 20-item measure meant to quickly assess energetic arousal and tense arousal. The four subscales across these dimensions are Energy (general activation), Tiredness (deactivation-sleep), Tension (high activation), and Calmness (general deactivation). Participants rated words such as “sleepy”. “jittery”, and “quiet” as either “definitely feel”, “slightly feel”, “do not feel”, or “does not apply.” .

Experimental Conditions

Participants completed the modified Stroop task on one day before exercise and completed the color word task on a second day before exercise. The order of tasks was randomized. When participants completed the modified Stroop color word task they were presented with a list of words where the printed word and ink color did not match. The words were presented on sheets of paper in two columns with 23 words in each column. Participants read all the way from top to bottom on the first column to the left before moving to the column on the right. Once participants were finished with one full sheet of 46 words they were presented with another sheet.. Participants were asked to state the ink color and not the printed word, except when the word was printed in red ink. In this case, participants were asked to state the word and to not say the color red as they otherwise would. The control condition color word task also had words printed in different colors of ink, but the words always matched the ink color. When participants made an error on either task they were told “no” and were required to go back to that word and give the correct response. Participants completed each task for 3 min 40 sec and were told to state as many words as possible as accurately as possible before being told to stop. The experimental condition was meant to deplete self-regulatory strength, whereas the control condition was not.

Procedure

On the first day, the study procedures were explained and participants read and signed an informed consent form. Demographic information was then collected and participants also completed the NHANES, which is a self-report measure of physical activity. Participants then performed a maximal exercise test on a treadmill. The exercise protocol was described first and then participants were fitted with a mouthpiece and nose plug for gas collection. The O_2 and CO_2 analyzers were calibrated for 30 min before each test to ensure proper function of the metabolic analysis system. Participants then started the test walking at a speed of 2.3 miles per hour (MPH) for three minutes. The speed of the treadmill then increased 0.4 mph every 3 minutes until volitional exhaustion. Heart rate and RPE were recorded at the end of every three minute stage during the test. The maximal exercise test was conducted so that ventilatory threshold could be determined for exercise on subsequent days. Ventilatory threshold, based on the method used by Davis et al. (1979) is found by using the maximal exercise test data and plotting the ventilatory equivalents for O_2 and CO_2 at different work rates and identifying the point of systematic increase in the ventilatory equivalent of O_2 without an equal increase in ventilatory CO_2. The Parvo Medics TrueOne 2400 metabolic measurement system was used to automatically identify this point. This marker of intensity has been used for exercise in research because it leads to many of the same psychological responses for exercisers regardless of fitness level (Ekkekakis, Hall, & Petruzzello, 2004).

For the second and third sessions, participants completed the modified Stroop task and the color word task before performing 30 minutes of treadmill exercise. The day that participants completed the color word task or the modified Stroop task will be randomized and counter-balanced. There was also a minimum of 72 hours between each of the sessions and each session occurred within three hours of the same time of day. The

Stroop was used in the Bray et al. (2008) study to reduce self-regulatory strength. Heart rate was taken before and after the task (modified Stroop, color word) and the ADACL was completed after each task. The presence of self-regulatory fatigue was indicated by an increase in heart rate from baseline to post-treatment and higher levels of fatigue reported on the ADACL after the modified Stroop task (experimental condition) than after the color word task (control condition). Participants then completed treadmill exercise conducted at the work rate associated with ventilatory threshold. The exercise session lasted 30 minutes in total, but participants only wore the mouthpiece and nose plug for gas collection during the first 9 minutes of the session. Participants performed at 50% of their work rate associated with ventilatory threshold for minutes 0-3, and at 80% of their ventilatory threshold work rate for minutes 3-6. Participants were then at their ventilatory threshold work rate for minutes 6-9 to verify with measures of VO_2 that ventilatory threshold was reached. After 9 minutes, the mouthpiece and nose plug were removed and participants stayed at the same work rate for the final 21 minutes. Participants were not told the time length of the session and all screens displaying exercise data were covered.

Data was collected in this study by recording participants' RPE and heart rate every three minutes during exercise. The researcher held up large pictorial depictions of the RPE scale and participants pointed to the number or phase that corresponded with their current feelings. The researcher then recorded their response on a data sheet. Heart rate was also monitored during the treatment (modified Stroop and color word task) using a heart rate monitor (Polar Electro Oy, Finland) and was recorded by the researcher on a data collection sheet every three minutes. The ADACL was completed by the participant with paper and pencil after the modified Stroop task and color word task. Data for each participant was collected independently. Data for each condition was saved in a separate file for each participant in a cabinet for analysis upon completion of the study.

Data Analysis

Descriptive statistics, including means and standard deviations, were reported in order to understand the distribution of RPE and ADACL scores among the sample. Paired-samples t-tests were used for each treatment condition to test for differences between participant's actual VO_2 recorded at the 9-minute mark of exercise and their target VO_2 for ventilatory threshold as determined by calculations based on the maximal exercise test. A paired samples t-test was also used to compare VO_2 between the two conditions. Repeated-measures analyses of variance (RM ANOVA) was used to determine if condition (modified Stroop, color word) altered physiological activation as assessed by the ADACL score. RM ANOVA was also used to determine if condition (modified Stroop, color word) altered the change in physiological activation (HR) as a function of time (pre-exercise, post-exercise). Related-samples t-tests were also used to determine differences in the number of correct answers given and accuracy between the modified Stroop task and color word task. Repeated-measures ANOVAs were also used to test RPE and HR as a function of the order that participants completed the pre-exercise depletion tasks (modified Stroop first, color word first), condition (modified Stroop, color word), and time.

CHAPTER IV

RESULTS

Participant Fitness and Physical Activity Level

Means and standard deviations of the Godin score, NHANES score, and VO_2 max are presented in Table 1. Data for each participant is listed in Table 2. Higher scores on the Godin and NHANES questionnaires indicate a higher level of physical activity.

Table 1

Descriptive Data for Godin Score, NHANES Score, and VO_2 Max

	Minimum	Maximum	Mean	Standard Deviation
Godin	19	52	33.46	11.21
NHANES	1.28	9.08	5.35	2.34
VO_2 Max	30	45	40.35	4.95

Table 2

Godin Score, NHANES Score, and VO_2 Max of Individual Participants

Participant	Sex	Godin Score	NHANES Score	VO_2 Max
1	M	23	7.32	45
2	M	27	4.71	44
3	M	46	4.27	39
4	M	37	3.96	42
5	M	27	5.41	44
6	M	45	9.07	44
7	M	19	1.71	44
8	M	35	7.63	36
9	F	24	4.32	31
10	F	35	5.18	39
11	F	52	6.60	42
12	F	19	1.28	30
13	F	46	7.98	37

Performance on the Maximal Exercise Test

Data was collected during the maximal exercise test to be compared to data from the experimental and control conditions. It took participants an average of 39.36 minutes to reach volitional exhaustion. RPE from each 3-minute segment of the maximal exercise test was averaged together for comparison with RPE data from the experimental and control conditions. Participants had an overall average RPE of 12.69 during the test. An independent-samples t-test was performed to test for baseline differences in RPE at 3 minutes of exercise. The group that completed the modified Stroop task the first day (*M* = 7.17, *SD* = 1.16) and the group that completed the modified Stroop task the second day (*M* = 7.14, *SD* = 1.06) did not significantly differ in RPE after 3 minutes of exercise, $t(11) = .03$, $p > .05$. The group that completed the color word task the first day (*M* = 6.50, *SD* = .54) and the group that completed that task the second day (*M* = 7.43, *SD* = 1.51) also did not differ in RPE at 3 minutes, $t(11) = -1.42$, $p > .05$. Finally, a paired-samples t-test revealed no significant difference for RPE at 3 minutes of exercise after completion of the modified Stroop task (*M* = 7.15, *SD* = 1.07) as compared to the color word task (*M* = 7.00, *SD* = 1.22), $t(12) = .56$, $p > .05$.

Verification of Ventilatory Threshold

Since workload assigned for the experimental and control condition was based on the treadmill speed at ventilatory threshold during the maximal exercise test, VO_2 was measured during the 9 minute warm-up of the experimental and control condition to assure that participants reached the VO_2 associated with their respective threshold. A paired-samples t-test was conducted to determine if the target VO_2 associated with ventilatory threshold was reached during the 9 minute warm-up of the experimental condition. The target VO_2 (*M* = 29.45, *SD* = 4.63) and the VO_2 recorded at the 9 minute mark of the 30 minute exercise session performed during the experimental condition (*M* = 28.40, *SD* = 3.44) were not significantly different, $t(12) = .911$, $p > .05$. A second paired-samples t-test was conducted to determine if the target VO_2 was significantly different from the VO_2 measured at the end of the warm-up of the control condition. The VO_2 recorded during the control condition (M = 28.38, SD = 4.13) was not significantly different from the target VO_2, $t(12) = 1.35$, $p > .05$. A final paired-samples t-test indicated non-significant differences in VO_2 at the 9 minute mark for the experimental group as compared to the control group, $t(12) = .03$, $p > .05$.

ADACL Score by Condition

A repeated-measures analysis of variance was conducted to determine if the Stroop task or color word task altered perceptions of energy and fatigue. It was predicted that participants would be more fatigued and more frustrated after completing the Stroop task (experimental condition) than after completing the color word task (control condition). Means and standard deviations for the subscales of the ADACL are presented in Table 3. The difference between the experimental and control conditions on the ADACL were not statistically significant, $F(1,12) = .93$, $p > .05$, partial $\eta^2 = .07$

Table 3

ADACL Means and Standard Deviations by Subscale

	Experimental Condition		Control Condition	
	M	*SD*	*M*	*SD*
Energy	13.00	3.49	13.62	3.64
Tiredness	9.77	4.02	9.31	4.89
Tension	9.62	4.31	8.54	3.23
Calmness	11.85	4.22	11.62	3.18

Heart Rate Response to the Modified Stroop and Color Word Task

Means and standard deviations are presented in Table 4. A 2 x 2 repeated-measures ANOVA for heart rate before and after the modified Stroop task and color word task indicated no significant main effect for condition, $F(1,8) = 0.10$, $p > .05$, partial $\eta^2 = .01$. There was, however, a significant main effect for time, $F(1,8) = 8.59$, $p < .05$, partial $\eta^2 = .52$. Heart rate was significantly higher than resting values after completing both the modified Stroop task and the color word task. Finally, the condition by time interaction was not significant, $F(1,8) = .97$, $p > .05$, partial $\eta^2 = .11$.

Table 4

Means and Standard Deviations of Heart Rate Before and After Task Completion

	Modified Stroop Task		Color Word Task	
Time	*M*	*SD*	*M*	*SD*
Before	72.73	6.78	72.46	8.04
After	74.80	7.07	77.08	12.84
Change	2.70	8.06	5.00	9.46

Performance Differences on the Stroop and Color Word Task

It was expected that the modified Stroop task would be more difficult to complete than the color word task. Thus, related-samples t tests were used to determine which task participants were able to complete more accurately and with fewer errors. A related-samples t test, $t(12) = -9.07$, $p < .05$, demonstrated that participants gave fewer correct answers for the Stroop ($M = 166.69$, $SD = 33.76$) than the color word task ($M = 394.77$, $SD = 93.41$). Participants also had significantly more wrong answers, $t(12) = 3.87$, $p<.05$, when completing the Stroop task ($M = 5.08$, $SD = 4.05$) compared to the color word task ($M = .92$, $SD = 1.26$).

RPE as a Function of Condition, Order, and Time

The primary objective of the study was to determine if depleting self-regulatory strength before exercise impacts RPE during exercise. RPE means and standard deviations for each three minute interval during exercise for each condition are listed in Table 5. The RPE means for the exercise completed after the experimental and control conditions are also presented in Figure 1. A 3-way repeated-measures ANOVA for RPE during exercise showed no significant main effect for condition, $F(1,11) = 3.51$, $p > .05$, partial $\eta^2 = .24$. The main effect for time was statistically significant, $F(9,3) = 31.24$, $p < .05$, partial $\eta^2 = .99$. RPE increased linearly from the beginning of each exercise session to the end. The main effect for order was also significant, $F(1,11) = 8.40$, $p < .05$, partial $\eta^2 = .43$. The 2-way condition by time interaction was not statistically significant, $F(9,3) = .66$, $p > .05$, partial $\eta^2 = .66$. The 2-way time by order interaction was not significant, $F(9,3) = .37$, $p > .05$, partial $\eta^2 = .52$. The 2-way condition by order interaction was significant, $F(1,11) = 9.01$, $p < .05$, partial $\eta^2 = .45$. Means and standard deviations are presented in Table 6. Participants who completed the modified Stroop task on the first day experienced a greater reduction in RPE on the second day than participants who completed the color word task on the first day. Finally, the 3-way condition by time by order interaction was not statistically significant, $F(9,3) = 1.14$, $p > .05$, partial $\eta^2 = .77$.

Table 5

Means and Standard Deviations of RPE for Condition and Time

	Experimental Condition		Control Condition	
minutes	*M*	*SD*	*M*	*SD*
3	7.15	1.07	7.00	1.23
6	9.46	1.51	9.38	1.66
9	11.15	1.28	11.31	1.75
12	12.00	1.80	11.92	1.38
15	13.08	.95	12.46	1.51
18	13.46	1.13	13.08	1.32
21	14.15	1.28	13.62	1.50
24	15.00	1.35	14.08	2.06
27	15.52	1.56	14.92	2.22
30	16.08	2.22	15.23	2.39

Figure 1: Rate of Perceived Exertion by Condition

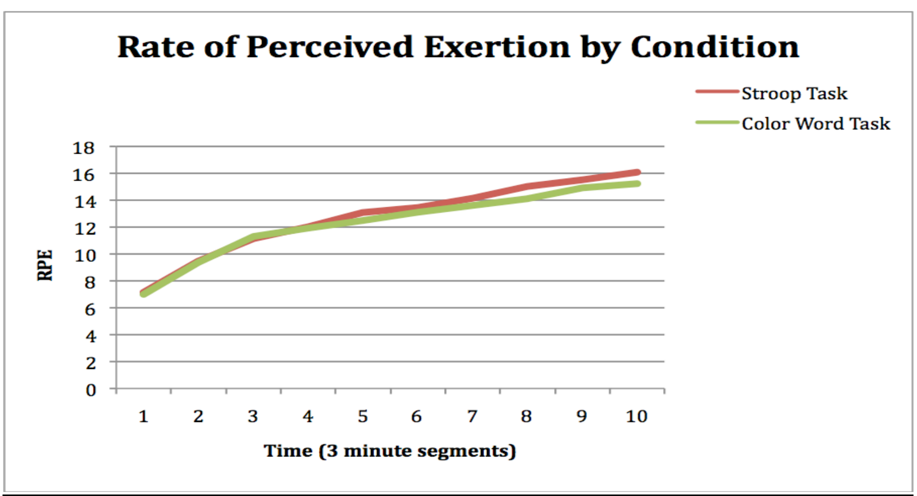

Table 6

Means and Standard Deviations of RPE for Condition and Order

	Modified Stroop Task		Color Word Task	
Order	*M*	*SD*	*M*	*SD*
Stroop first	12.50	.68	11.27	1.07
Color word first	12.90	.63	13.19	.99

Heart Rate as a Function of Condition, Order, and Time

A secondary objective was to determine if heart rate during the exercise session was different as a result of experiencing diminished self-regulatory strength. Heart rate was measured every three minutes during exercise and means and standard deviations for each condition are presented in Table 7. A 3-way repeated-measures ANOVA for heart during exercise showed no significant main effect for condition, $F(1,10) = .05$, $p > .05$, partial $\eta^2 = .01$. The main effect for time was statistically significant, $F(9,2) = 29.14$, $p < .05$, partial $\eta^2 = .99$. Heart rate increased linearly from the beginning of each exercise session to the end. The main effect for order was not statistically significant, $F(1,10) = 2.50$, $p > .05$, partial $\eta^2 = .20$. The 2-way condition by time interaction was not statistically significant, $F(9,2) = 1.08$, $p > .05$, partial $\eta^2 = .82$. The 2-way time by order interaction was not significant, $F(9,2) = 12.98$, $p > .05$, partial $\eta^2 = .98$. The 2-way condition by order interaction also was not significant, $F(1,10) = .84$, $p > .05$, partial $\eta^2 =$

.07. Finally, the 3-way condition by time by order interaction was not statistically significant, $F(9,2) = .39$, $p > .05$, partial $\eta^2 = .64$.

Table 7

Means and Standard Deviations of Heart Rate for Condition and Time

	Stroop Task		Color Word Task	
minutes	*M*	*SD*	*M*	*SD*
3	94.67	6.51	96.33	8.32
6	123.83	17.36	123.00	16.34
9	149.42	11.43	146.00	14.67
12	155.75	12.87	152.75	15.52
15	156.75	14.72	157.33	17.31
18	159.67	14.88	159.33	16.24
21	159.00	15.89	161.00	15.02
24	160.25	14.07	162.42	16.03
27	162.08	15.42	162.33	16.03
30	164.67	14.36	164.33	15.96

CHAPTER V

DISCUSSION

The primary purpose of this research was to determine if self-regulatory strength depletion, induced by completion of the Stroop task, increased ratings of perceived exertion during a 30-minute session of treadmill exercise. Past research (Bray et al., 2007; Muraven et al., 1998) has demonstrated that time to volitional exhaustion on handgrip exercise is shortened when participants have been depleted of self-regulatory strength. The effects of self-regulatory strength depletion on other exercise modalities or for exercise bouts longer than several minutes have not been studied. Yet ACSM guidelines recommend that individuals perform cardiovascular exercise for 30 minutes at a time (Haskell et al., 2007), and this recommendation is different in duration, modality, and intensity than handgrip exercise. Thus, the goal of the current study was to replicate and extend the work of Bray et al. (2007) by examining if self-regulatory strength depletion before exercise impacts performance for an exercise task (30 minutes of treadmill running at a moderate intensity) that could be performed by individuals attempting to meet ACSM recommendations.

Past researchers (Bray et al., 2007; Muraven et al., 1998) have found that self-regulatory strength depletion impacts performance on a second task requiring self-regulatory strength immediately after depletion, but that finding was not replicated in the present study. RPE and heart rate did significantly increase throughout both exercise conditions as a function of time, but RPE and heart rate were not significantly different between the experimental and control conditions. Thus, self-regulatory strength depletion did not impact objective exertion, as measured by heart rate, or subjective exertion as measured by RPE. These were unexpected findings because Bray et al. (2007) did find significant performance decrements on a handgrip task after participants completed a task that depleted self-regulatory strength. The present study did employ the same self-regulatory strength depletion task as Bray et al., but used a different exercise task. The exercise intensity was also different. Participants in the present study were asked to exercise at ventilatory threshold, whereas participants in the Bray et al. study held 50% of the force they could produce on one maximum voluntary contraction until failure. It is also unknown if the different durations of the exercise sessions allowed self-regulatory strength to recover during the warm-up portion of exercise when participants probably didn't need to use as much self-regulatory strength to continue exercising. Participants in the Bray et al. study did the handgrip for less than 5 minutes and participants in the present study were on the treadmill for 30 minutes. Some or all of these differences could have resulted in the failure to replicate a main effect for experimental condition.

However, results from this study indicate that perceived exertion during 30 minutes of exercise is impacted by self-regulatory strength depletion, but that this effect is only evident when considered in combination with exposure to two exercise sessions. In particular, participants who completed the experimental session on the first day reported lower RPE on their second day of exercise than participants who completed the control condition on the first day. Self-regulatory strength depletion did not immediately impact RPE, but may have rather led participants to expect that the second exercise session would feel as difficult as the first one where they had been depleted of self-regulatory strength. This interpretation is based on the finding that participants who completed the modified Stroop task on the first day experienced a greater reduction in RPE on the second day than participants who completed the color word task on the first day. Exercise on the second day likely resulted in a lower RPE because participants were not depleted of self-regulatory strength and they were familiar with the type of exercise that they would be expected to do. Participants who first completed the control condition, however, may have expected that exercise the second day would be similar to the first. Yet these participants experienced a significantly smaller reduction in RPE perhaps because they were depleted of self-regulatory strength. Although this finding is not precisely consistent with the findings of past research, it does suggest that self-regulatory strength depletion has a more subtle influence on perceived exertion during a 30-min aerobic exercise bout. Past researchers (Bray et al., 2007; Marcora et al., 2009; Muraven et al., 1998) have used between-subjects designs and thus have not measured how individuals react to self-regulatory strength depletion over several days. Future research studies should systematically deplete self-regulatory strength and measure RPE on subsequent days during exercise to determine how long the effects on perceived exertion last after the initial depletion. Future researchers should also measure how RPE changes between exercise sessions when participants complete the same task (modified Stroop, color word) on both days before exercise.

Although many different manipulations have been used to deplete self-regulatory strength in past studies (Baumeister et al., 2007; Muraven et al., 1998), Bray et al. (2007) used the modified Stroop task to deplete self-regulatory strength. The modified Stroop task was also used in the present study to deplete self-regulatory strength and the color word task was used as the control condition. It is expected that when self-regulatory strength is depleted, participants will experience increased feelings of fatigue (Muraven & Baumeister, 2000). Therefore, it is customary to use a manipulation check to compare tasks that are supposed to deplete self-regulatory strength with tasks that do not. In the present study, participants completed the ADACL (Thayer, 1989) after the modified Stroop task and after the color word task. The ADACL measures perceptions of energy, tiredness, tension, and calmness, and it was expected that participants would report higher scores of tiredness and tension and lower scores of energy and calmness after they completed the modified Stroop task. There were, however, no differences on ADACL score between participants after they completed the modified Stroop task or the color word task. This indicates either that the modified Stroop task did not deplete self-regulatory strength, that both tasks affected self-regulatory strength equally, or that the ADACL was not sensitive enough to record perceptions of depleted self-regulatory strength. Regardless, the non-significant results for the ADACL may indicate that the treatment conditions did not actually differ in terms of self-regulatory strength. Given the non-significant findings of the manipulation check, it is difficult to determine why participants experienced elevated RPE during the control condition when they had been depleted of self-regulatory strength several days prior, but not during exercise directly after depletion. Future research should clarify the best way to measure self-regulatory strength so that depletion can be tracked over time in response to different tasks.

Past research (Bray et al., 2007; Muraven et al., 1998) has also not measured performance on the self-regulatory strength depletion task and has only measured the feelings of fatigue and frustration that resulted from completing the task. The typical protocol for these studies (Bray et al., 2007; Muraven et al., 1998) is to ask participants to complete the self-regulatory strength depletion task for a set amount of time. The present study used the same manipulation as Bray et al. and asked participants to complete as many words as possible during the modified Stroop task or color word task over 3 min 40 sec. Participants were told to complete words both as quickly and accurately as possible. Performance, however, was measured during the present study and it was found that participants completed fewer words during the modified Stroop task than the color word task. Participants also gave more wrong answers during the modified Stroop task than the color word task. It is not clear how these performance differences between the modified Stroop and color word task influenced self-regulatory strength depletion because Bray et al. did not measure performance on the depletion task.

Past studies (Baumeister et al., 2007; Muraven & Baumeister, 2000) also have not determined a dose-response relationship for self-regulatory strength and the time it takes for self-regulatory abilities to return to full capacity. Participants in the Bray et al. (2007) study were only able to hold 50% of their maximum voluntary contraction on an isometric handgrip task for less than 50 seconds. Participants in the present study had a 6-

minute warm-up before the speed associated with ventilatory threshold was even attained. It is possible that self-regulatory strength depleted by the Stroop task was restored during the warm-up period of exercise and that once ventilatory threshold was reached, participants who completed both the Stroop task and color word task had equal amounts of self-regulatory strength. Since the manipulation (modified Stroop task) in the Bray et al. (2007) study was completed for 3 minutes 40 seconds and took almost four times longer to complete than the exercise task (50 seconds), future research should use self-regulatory strength depletion tasks that last for a longer period of time. In future studies, the depletion task should last at least as long as the exercise task. It’s also possible that asking participants to complete a self-regulatory strength depletion manipulation during exercise would result in even more robust effects. Finally, future research should clearly define the extent to which certain tasks deplete self-regulatory strength and how long it takes this depleted strength to be restored.

The assignment of exercise intensity may also have contributed to the insignificant findings for RPE on the initial day of self-regulatory strength depletion. The present research study was designed with ventilatory threshold as the exercise intensity. After a 6-minute warm-up, participants ran at the treadmill speed associated with their ventilatory threshold for the last 24 minutes of exercise. This treadmill speed was based on measurements from each participant’s VO_2 maximal exercise test. Ventilatory threshold was the chosen exercise intensity because past research (Ekkekakis et al., 2004) has demonstrated that exercise affective responses are universally positive before the ventilatory threshold is crossed, but universally negative at exercise intensities above the ventilatory threshold. Since ratings of perceived exertion are influenced by affect (Hutchinson & Tenenbaum, 2006) it was believed that exercise above or below the ventilatory threshold would result in universally high or low ratings of perceived exertion that were independent of any perceptions of self-regulatory strength depletion. Thus, it seemed that self-regulatory strength depletion would have the greatest impact on RPE right at ventilatory threshold. At this intensity, perceptions of exercise are neither universally positive nor negative (Ekkekakis et al., 2004). However, since past researchers (Ekkekakis et al., 2004) have argued that ventilatory threshold is such a difficult point to identify, perhaps future research should choose to have all participants exercise either significantly above or significantly below ventilatory threshold. This would assure that slight errors in identifying ventilatory threshold do not lead some participants to be assigned exercise workloads that place them slightly above ventilatory threshold, and others given exercise slightly below ventilatory threshold. Small errors in identification of the threshold could lead to participants giving vastly different ratings of affect and RPE, because they would either be above or below the threshold and not right at it. Yet if the target intensity were significantly above or below the threshold, small errors would assure that the participant's exercise intensity does not cross the threshold in either direction.

Conclusions

The present research has indicated that self-regulatory strength depletion does not increase RPE during 30 minutes of treadmill exercise at ventilatory threshold, but rather makes future exercise sessions feel easier when individuals are not depleted. If exercisers have not been previously depleted, they will report higher RPE than if they had experienced some self-regulatory strength depletion during prior exercise experiences. The finding that RPE is not impacted directly after self-regulatory strength depletion is unexpected based on the similar work of Bray et al. (2007) and Marcora et al. (2009). It is not clear why participants did not report higher perceived exertion on the very day that self-regulatory strength was depleted, but only reported higher RPE in later exercise sessions. In future studies, researchers should determine better ways to measure and quantify self-regulatory strength so that it can be easily determined when depletion has occurred.

If the results of the present study are accepted, than several implications should follow. Since past self-regulatory strength depletion results in a lower RPE than would be expected for future exercise sessions where self-regulatory strength is not depleted, individuals should sometimes train when self-regulatory strength has been depleted. Athletes in sports where performance is impacted by RPE should deplete self-regulatory strength during practice sessions. When peaking, these athletes would avoid activities that deplete self-regulatory strength and should experience lower RPE during competition than if they had not experienced prior self-regulatory strength depletion during training. Conversely, exercisers who have no experience with self-regulatory strength depletion will be especially sensitive to the effects of depletion on RPE. But individuals who experience regular depletion of self-regulatory strength should be able to perform moderate intensity exercise and not experience abnormally high perceptions of fatigue or exertion. But if these individuals who are used to being depleted exercise when they are not depleted, they should experience a lower RPE than would be expected if they were experiencing depletion for the first time. These results should be interpreted with caution until an accepted method to measure self-regulatory strength depletion is created so that depletion can be tracked over time.

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APPENDIX A

AHA/ACSM HEALTH/FITNESS FACILITY PRE-PARTICIPATION SCREENING QUESTIONNAIRE

Please mark all statements that are *true*

History

You have had:

____ a heart attack

____ heart surgery

____ cardiac catheterization

____ coronary angioplasty (PTCA)

____ pacemaker/implantable cardiac

____ defibrillator/rhythm disturbance

____ heart valve disease

____ heart failure

____ heart transplantation

____ congenital heart disease

*If any symptoms marked in this section please consult physician

Symptoms

____ You experience chest discomfort with exertion.

____ You experience unreasonable breathlessness.

____ You experience dizziness, fainting, or blackouts.

____ You take heart medications

Other health issues

____ You have diabetes.

____ You have asthma or other lung disease.

____ You have burning or cramping sensation in your lower legs when walking short distances.

____ You have musculoskeletal problems that limit your physical activity.

____ You have concerns about the safety of exercise.

____ You take prescription medication(s).

____ You are pregnant.

Cardiovascular risk factors

____ You are a man older than 45 years.

____ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal.

____ You smoke, or quit smoking within the previous 6 months.

____ Your blood pressure is >140/90 mm Hg.

___ You do not know your blood pressure.

*If 2 or more statements marked in this section please consult physician

____ You take blood pressure medication.

____ Your blood cholesterol level is >200 mg/d

____ You do not know your cholesterol level.

____ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister).

____ You are physically inactive (i.e. – you get <30 minutes of physical activity on at least 3 days per week).

____ You are >20 pounds overweight.

APPENDIX B

LEISURE TIME EXERCISE QUESTIONNIARE

Considering a typical 7-day period (a week), how many times on the average do you do the following kinds of exercise for more than 15 minutes during your free time?

Please use the following scale.

0 = never
1 = 1 time a week
2 = 2 times a week
3 = 3 times a week
4 = 4 times a week
5 = 5 times a week
6 = 6 times a week
7 = 7 times a week
8 = 8 times or more a week

1. Strenuous exercise (Heart beats rapidly) (i.e. running, jogging, hockey, football, soccer, squash, basketball, x-country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)

0 1 2 3 4 5 6 7 8

2. Moderate exercise (Not exhausting) (i.e. fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)

0 1 2 3 4 5 6 7 8

3. Mild exercise (Minimal effort) (i.e. yoga, archery, fishing from river bend, bowling, horseshoes, golf, snowmobiling, easy walking)

0 1 2 3 4 5 6 7 8

APPENDIX C

DEMOGRAPHICS

Age: _____ Date of Birth: _____________ Sex: Male Female

Ethnic Background: African American/Black Asian/Pacific Islander

Caucasian/White Hispanic

Native American Other: _____________________

Education Completed: College/Secondary School: 1 2 3 4

Degree program: __________________________________

Graduate School: Yes/No

If Yes, then degree: ________________________________

Have you completed the Stroop task before: Yes No

If Yes, please estimate when and how many times you have completed the Stroop task:

____

____

____

____

APPENDIX D

NHANES

In the past 2 weeks, have you done any of the following exercises (yes or no)?	How many times in the past 2 weeks did you complete the activity?	On average, about how many minutes did you actually spend doing the activity?	What usually happened to your heart rate? Small increase, moderate increase, large increase, no increase, or don't know
Walking for exercise?	_______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Gardening or yard work?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Stretching exercise?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Weightlifting or other exercise to increase muscle strength?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Jogging or running?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Aerobics or dance?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Riding a bike?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Stair climbing for exercise?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK

Swimming?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Tennis?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Golf?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Bowling?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Baseball or softball?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Handball, racquetball, or squash?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Skiing?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Downhill?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Cross-Country?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Water?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Basketball?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Volleyball?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Soccer?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK
Football?	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK

Other physically active hobbies	______ Times	___ Minutes	_Sm, _Mod, _ Lrg, _None, _DK

APPENDIX E

ACTIVATION-DEACTIVATION ADJECTIVE CHECK LIST

Each of the words listed below describes feelings or mood. Please use the rating scale net to each word to describe your feelings at this moment.

Examples:

Relaxed **vv** v ? no	If you circle the double check (vv) it means that you *definitely* feel relaxed *at the moment.*
Relaxed vv **v** ? no	If you circle the single check (v) it means that you feel slightly relaxed *at the moment.*
Relaxed vv v **?** no	If you circle the question mark (?) it means that the word does not apply or that you cannot decide if you feel relaxed *at the moment.*
Relaxed vv v ? **no**	If you circle the no it means that you are *definitely not relaxed at the moment.*

Work rapidly, but please mark all the words. Your first reaction is best. This should take only a minute or two.

1. active	vv v ? no	11. drowsy	vv v ? no
2. placid	vv v ? no	12. fearful	vv v ? no
3. sleepy	vv v ? no	13. lively	vv v ? no
4. jittery	vv v ? no	14. still	vv v ? no
5. energetic	vv v ? no	15. wide-awake	vv v ? no
6. intense	vv v ? no	16. clutched-up	vv v ? no
7. calm	vv v ? no	17. quiet	vv v ? no
8. tired	vv v ? no	18. full of pep	vv v ? no
9. vigorous	vv v ? no	19. tense	vv v ? no
10. at-rest	vv v ? no	20. wakeful	vv v ? no